7. Using Bacteria Criteria as Indicators of Water Quality

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This chapter addresses the role of bacteria criteria in determining attainment of applicable water quality standards (WQS) and listing impaired waters. The chapter provides a framework for states' assessment and listing methodologies. The information that states should provide about assessment methods includes:

- How are bacteria criteria used within the context of the state's WQS?
- How does the state define and then evaluate the quality of bacteria criteria sets from primary and secondary sources?
- How does the state interpret bacteria criteria to assess WQS attainment or nonattainment?
- How does the state use predictive tools to support attainment decisions?

7.1 How Are Bacteria Criteria Used Within the Context of the State's Water Quality Standards?

Under the Clean Water Act (CWA), states must establish WQS for all waters within their jurisdiction. A WQS defines a use (or uses) for a waterbody and describes the specific water quality criteria to achieve that use. In establishing WQS, states must (1) designate uses consistent with CWA goals, (2) establish water quality criteria to protect the uses, and (3) develop and implement antidegradation policies and procedures. States are also expected to develop implementation procedures for the WQS. These procedures address mechanisms for assessing attainment with the WQS as well as translation of the WQS to an NPDES permit limit.

States generally use bacteria data to develop water quality criteria to protect three designated uses: recreation, shellfish consumption, and public water supply. Responsibility for protecting these designated uses is typically distributed among multiple state and local agencies. Therefore, state water quality agencies frequently rely on interpretation of bacteria data collected and analyzed by other agencies when making designated use support determinations under CWA sections 303(d) and 305(b). For example, state and local public health departments are usually responsible for monitoring to ensure waters are suitable for recreation and shellfish harvesting. Drinking water officials may collect data on the condition of a drinking water supply's source. The state should use the information collected by these different entities in making designated use support decisions.

7.1.1 Recreational Designated Use

Recreational designated uses include swimming, wading, boating, surfing, and other activities in which people come into full or partial contact with surface waters. Waters may be assigned a general recreational use designation. Some states differentiate among types of recreational uses and designate waters for specific subcategories of recreational uses. EPA's *Implementation Guidance for Ambient Water Quality Criteria for Bacteria* provides more detail about options for adopting subcategories of recreational uses (U.S. EPA 2002 - projected).

Based on a risk management approach to protecting recreational uses of surface waters, EPA's recommendation is to use *E. coli* and enterococci as bacteria indicators as described in Ambient Water Quality Criteria for Bacteria - 1986. Table 7-1 summarizes the current section 304(a) criteria recommendations related to bacteria indicators for fresh waters and marine waters. The criteria values are based on levels of risk correlating to no more than 8 cases of acute gastrointestinal illness per 1,000 swimmers for fresh waters and no more than 19 illnesses per 1,000 swimmers for marine waters (U.S. EPA 1986). States may exercise risk management discretion and adopt criteria based on illness rates up to 19 illnesses per 1,000 swimmers. The *Implementation Guidance for Ambient Water Quality Criteria for Bacteria* provides calculations of criteria based on different risk levels.

Many states still use the pre-1986 standard for fecal coliform as the numeric criterion to protect recreational uses. EPA recommends state transition to the *E. coli* and enterococci criteria because these bacteria indicators correlate more strongly to gastrointestinal problems than does the fecal coliform indicator. Recent amendments to the CWA have placed additional requirements on states with coastal and Great Lakes waters to adopt water quality criteria consistent with EPA recommendations for recreational waters to protect beaches specifically. EPA encourages states to adopt these criteria to protect all recreational waters.

7.1.2 Shellfish Consumption Designated Use

Fish and shellfish consumption is a beneficial use protected under the Clean Water Act. Waters where shellfish may be harvested for human consumption are protected by numeric water quality criteria aimed at preventing public health risks associated with bacteria contamination. The numeric human health criteria for water column concentrations of bacteria indicators that are outlined in Quality Criteria for Water (U.S. EPA 1977) may be used as a basis for determining impairment to shellfish waters (see Table 7-1). These criteria are consistent with those used by the National Shellfish Sanitation Program.

7.1.3 Public Water Supply Designated Use

EPA and states protect waters used as drinking water supplies under both the Safe Drinking Water Act (SWDA) and the CWA. Under the SDWA, EPA develops National Primary Drinking Water Regulations. Some of these address source water quality, although most address the quality of treated drinking water. The SDWA also addresses the protection of source waters through state planning activities including the Source Water Protection Plans and Wellhead Protection Plans. Under the CWA, states protect waters designated as public water supplies by adopting criteria sufficient to protect the use.

Table 7-1. Current water quality criteria for bacteria indicators

Designated use	Bacteria indicators evaluated	Criteria
Primary contact recreation	*E. coli*[a]	Freshwater geometric mean: not to exceed 126 CFU per 100 mL, based on no fewer than five samples equally spaced over a 30-day period. Freshwater single-sample maximum: no sample should exceed a one-sided CL calculated using 235 CFU/100 mL (designated bathing beach) 75% CL; 298 CFU/100 mL (moderate use for bathing) 82% CL; 406 CFU/100 mL (light use for bathing) 90% CL; 576 CFU/100 mL (infrequent use for bathing) 95% CL; based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.4 as the log standard.
	Enterococci[a]	Freshwater geometric mean: geometric mean not to exceed 33 CFU per 100 mL, based on no fewer than five samples equally spaced over a 30-day period. Freshwater-single sample-maximum: no sample should exceed a one-sided CL calculated using 61 CFU/100 mL (designated bathing beach) 75% CL; 89 CFU/100 mL (moderate use for bathing) 82% CL; 108 CFU/100 mL (light use for bathing) 90% CL; 151 CFU/100 mL (infrequent use for bathing) 95% CL; based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.4 as the log standard. Marine geometric mean: geometric mean not to exceed 35 CFU per 100 mL, based on no fewer than five samples equally spaced over a 30-day period. Marine single-sample maximum: no sample should exceed a one-sided CL calculated using 104 CFU/100 mL (designated bathing beach) 75% CL; 158 CFU/100 mL. (moderate use for bathing) 82% CL; 276 CFU/100 mL (light use for bathing) 90% CL; 500 CFU/100 mL (infrequent use for bathing) 95% CL; based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.7 as the log standard.
Secondary contact recreation		Adopt criteria commensurate with anticipated use, not to exceed five times the geometric mean values used for primary contact recreation.[b]
Shellfish harvesting	Total coliform[c]	Geometric mean of 70 most probable number (MPN) per 100 mL, with not more than 10% of the samples taken during any 30-day period exceeding 230 MPN per 100 mL.
	Fecal coliform[c]	Median concentration should not exceed 14 MPN per 100 mL, with not more than 10% of the samples taken during any 30-day period exceeding 43 MPN per 100 mL.
Public drinking water sources		Ambient criteria are under development.

[a] Source: U.S. EPA 1987.
[b] Source: U.S. EPA 2002.
[c] Source: U.S. EPA 1977.

Standards applicable to treated drinking water are outlined in 40 CFR 141.71(a)(1). States may wish to adopt these values into their WQS to protect waters designated as public water supplies. EPA is also working on standards that apply to drinking water sources.

The presence of bacteria in treated drinking water, on the basis of fecal indicators or other bacteria indicators, shows that the water may be unsafe for consumption. Thus, EPA has set the maximum contaminant level goal at zero for *Cryptosporidium* and *Giardia lamblia*, total coliforms, and viruses for treated water distributed by public drinking water systems (40 CFR 141.74). Water quality criteria have not been developed for these bacteria indicators in surface waters used as drinking water supply. Most protozoa, viruses, and bacteria are inactivated by chlorine or other disinfectants used during the treatment process, although some human bacteria are more resistant to disinfection than others. All disinfection and filtration technologies are designed to remove a portion, but not all, of bacteria contamination from the influent. Therefore, higher levels of bacteria in the source water potentially translate into contamination levels in the treated water and thus pose a greater public risk.

7.2 What Are the Data Quality and Documentation Requirements for Bacteria Criteria From Primary and Secondary Data Sources?

A state's assessment methodology should document data quality requirements so that all interested parties may contribute relevant data. States should include this information in their standard operating procedures (SOPs) or Quality Assurance Project Plans (QAPPs). The assessment methodology may reference these other documents instead of reiterating the state's requirements.

7.2.1 What Are the State's Requirements for Sample Collection and Analytical Methods And/or Performance Criteria for Analytical Methods?

Adherence to specific procedures for sampling is recommended for a successful and effective water quality monitoring program. Collection, preservation, and storage of water samples are critical to the results of analyses for bacteria indicators. Detailed guidance on sample collection and analytical techniques is available at *http://www.epa.gov/microbes*.

7.2.2 What Is the State's Process for Evaluating the Quality of Bacteria Criteria?

Data quality assessment means the scientific and statistical evaluation of data to determine whether data obtained from monitoring operations are of the right type, quality, and quantity to support water quality assessments. Data quality does not exist in a vacuum; one must know in what context a data set is to be used in order to establish a relevant yardstick for judging whether the data set is adequate.

For assessing WQS attainment, EPA recommends a tiered approach. The following steps should be part of the first tier of the data quality review process.

- Were data generated using appropriate sampling and analysis methods?
- Were samples collected under the appropriate conditions for comparison with WQS (e.g., correct time of year or flow conditions)?
- Is there documentation to show that sampling and analysis results were evaluated according to QAPPs or other project requirements?
- Is there quality control information with the data set?
- What are the limitations of the data, and are the data usable with those limitations?
- Do data meet assessment needs?
- Do the metadata accompanying the data set meet agency standards (e.g., determine adequacy and accuracy of geographic documentation in the data set)?

Once the state determines that the data set meets basic documentation requirements, the data set is ready for analysis to support WQS attainment decisions. In some cases, the state may decide additional screening is necessary before the data set is ready to support attainment decisions. For example, the state may want to look for values below the detection limit of the analytical method, because these may influence how the data set is analyzed or incorporated into other data sets. If upon initial analysis of the data, the findings raise suspicions about possible errors in collection or analysis, the state may want to conduct more in-depth analysis of quality assurance/quality control (QA/QC) procedures. This screening could include reviews of QA/QC reports to determine whether the data set meets the agency's QA/QC requirements regarding: documenting measurement system performance (e.g., adequate use of QC samples), handling missing data and nondetects, and deviations from SOPs. Guidance for assessing the quality of available data sets is described in detail in Practical Methods for Data Quality Assessment (EPA/600/R-96/084).

7.2.3 How Does the State Document the Level of Data Available To Support an Attainment/Impairment Decision?

The 305(b) Consistency Workgroup developed a table assigning qualitative levels of information or data quality to different types of chemical data. Several states have since developed similar approaches for rating the quality of data used in WQS assessments. States are encouraged to use an approach similar to that described in Table 4-2 to report on the quality of data supporting attainment/impairment decisions. In addition, they should begin documenting quantitative information about the quality of these decisions.

The data hierarchy described in Table 4-2 addresses data quality considerations such as sample collection and analytical techniques, spatial and temporal representativeness, and QA procedures. The user rates the data set on the basis of the rigor of the information, where 1 is the lowest and 4 is the highest. In general under this approach, Level 1 information alone is not sufficient for an attainment decision; however, even a short period of record can indicate impairment in cases of gross exceedances of criteria.

States should supplement the data descriptions in Table 4-2 with more quantitative descriptions of the confidence and power of their attainment/impairment decisions. This documentation clearly illustrates to decision makers and the public the impact of small data sets on uncertainty in the water quality decision. Quantitative documentation of the uncertainty is expressed in statistical terms of the error rates, both Type I decision error, or the α-level, and Type II decision error, or the β-level, of the assessment. These decision errors are discussed in detail in Appendices C and D. A Type I error occurs when an attaining waterbody is erroneously judged to be impaired, and a Type II error occurs when an impaired waterbody is erroneously judged to be attaining. EPA encourages states to collect sufficient numbers of samples to balance both types of error at reasonable levels.

To summarize, for attainment decisions based on chemical data, States should document:

- Level of information based on Table 4-2 or state-developed table or approach
- Sample size, range of concentrations, mean, median, and standard deviation
- Level of statistical confidence (Type I decision error and Type II error) and width of the confidence interval.

7.3 How Does the State Interpret Bacteria Criteria To Assess WQS Attainment/Impairment?

Once the state has assembled data that meet its data quality requirements, it analyzes the data in order to compare them with applicable state standards. The state's consolidated assessment and listing methodology should describe its process for interpreting data to make WQS attainment decisions. This section focuses on data analysis. The next section addresses the use of predictive tools. Chapter 3 deals with integration of bacteria indicator and other data to assess individual designated uses, including recreation, public water supply, and shellfish consumption. It is important that the State's methodology describe all of the approaches it uses to assess data and information when it makes WQS attainment decisions.

7.3.1 How Does the State Process the Data Set?

Water quality measurements from natural systems occur in natural patterns that can be considered a distribution of values. When the data values fall in a systematic pattern around the mean and then taper off rapidly to the tails, it is called a normal distribution or bell-shaped curve. However, in some instances, a log-normal distribution, which has a more skewed (lopsided) shape than normal, occurs. The log-normal is bounded by zero and has a fatter tail than the normal. When sampled data take the shape of a log-normal distribution, it is common practice to transform data to achieve approximate normality prior to conducting statistical tests. In most instances the data values for *E. coli* and enterococci, for example, will be log-normally distributed, hence the state should transform the data and apply the geometric mean. Appendix C provides additional information on analysis of log-normal data sets.

7.3.2 How Does the State Analyze Bacteria Criteria and Compare the Findings With the Applicable Criteria?

Many states have not yet documented implementation procedures that describe how they will collect and interpret water quality data to assess attainment with applicable WQS in the ambient environment. In lieu of these procedures, states often summarize the available bacteria criteria and compare the results directly with applicable WQS. A majority of states use the recommendations of the 305(b) Consistency Workgroup to assist in making designated use support determinations (U.S. EPA 1997). The CALM document, along with the new implementation guidance for bacteria criteria, is intended to provide a framework for states to build from the 305(b) recommendations, document an assessment and listing methodology, and incorporate it into the state's WQS implementation policies.

Many states are moving forward in documenting how WQS attainment decisions are made. States are developing or revising WQS implementation policies to address the variability and uncertainty associated with monitoring water quality conditions. These implementation policies address:

- Desired confidence levels in the data used to support the decision
- Appropriate size of confidence intervals to control the precision of the data set
- Minimum sample size to control for the potential to conclude that a waterbody is attaining a standard when insufficient data have been collected to credibly detect nonattainment.

All three factors should be included in the state's methodology for interpreting WQS. These factors, in combination, allow the state to reflect the sensitivity of the statistical analysis, balance decision error, and control the precision of WQS attainment decisions. These procedures should be referenced in the state, territory or authorized tribe's approved WQS or in other implementing regulations or policies and procedures documents such as the continuous planning process or consolidated assessment and listing methodology.

Equally important is ensuring that sufficient resources are available for monitoring activities needed to collect data that meet the state's decision making needs. These resources may come from a variety of sources, including state water quality agency budgets, EPA grants, and other monitoring partners in the public, private, academic, and volunteer sectors. Until sufficient resources are in place, states should develop contingencies for how attainment decisions will be made when the data set does not meet these objectives. Some states target these waters for additional monitoring in the short term (see text box).

A state has developed implementation procedures for remote waters that are not designated as public beaches. The procedures use the single-sample maximum as a trigger for collecting five samples within a 30-day period. If the routine monitoring finds an exceedance of a single-sample maximum, then the state collects additional samples to calculate the geometric mean. Then the state uses the geometric mean to make an attainment/nonattainment decision (i.e., both the geometric mean and the single-sample maximum need to exceed the state standard for the waterbody to be identified as impaired under 305(b) and 303(d)).

The 1997 guidelines for preparing 305(b) reports include recommendations for using bacteria criteria in making decisions about attainment of primary contact recreation water quality criteria. The decision rules for interpreting bacteria criteria that were recommended in these guidelines are summarized in Table 7-2. These rules have been modified for presentation in this table by combining the partially supporting and not supporting categories under the impaired category.

The 305(b) guidelines do not contain similar decision rules for assessing bacteria criteria to determine attainment with the shellfish harvesting use or public water supply use. The 305(b) recommendations for assessing attainment with these uses focus on using advisory or closure notices to support attainment decisions. This procedure is discussed in more detail in Chapter 3.

Table 7-2. Using bacteria criteria to support WQS attainment decisions for primary contact recreation

Bacteria indicators	**Attaining WQS**	**Impaired**
Enterococci	Geometric mean and the single-sample maximum are met	Geometric mean is exceeded or single-sample maximum is exceeded during recreational season
E. coli	Geometric mean and the single-sample maximum are met	Geometric mean is exceeded or single-sample maximum is exceeded during recreational season
Fecal coliform	Geometric mean is met and no more than 10% of samples exceed single-sample maximum	Geometric mean is exceeded or more than 10% of samples exceed single-sample maximum

Other environmental data such as salinity, temperature, turbidity, and rainfall might provide further insights into interpretation of the data obtained; however, they do not serve as independent indicators of possible health risks. For example, if the salinity of the water off an ocean beach is lower than normal, perhaps additional flow from a point-source discharge or nonpoint runoff was present. Abnormally cold water temperatures could stress microorganisms collected in the samples, and procedures to recover stressed microorganisms might not accurately measure bacteria indicator density. High turbidity often coincides with a higher density of microbiological organisms. Drinking water treatment plants use information on seasonal fluctuations of turbidity to adjust treatment for optimal removal of microbial contaminants.

The role of rainfall data in predicting bacteria indicator density is discussed in the next section.

7.4 How Does the State Use Predictive Tools To Support WQS Attainment Decisions?

A variety of predictive tools can be used to assess attainment and evaluate the need for beach or shellfish harvesting closures, advisories, and warnings. This section contains descriptions of several such tools, including their attributes, limitations, input data requirements, and availability.

Although most states do not use precautionary advisories or closures when making WQS attainment/impairment decisions, they may use the results of calibrated predictive tools to support WQS attainment/impairment decisions. The assessment and listing methodology should describe how the State uses these tools.

7.4.1 Predictive Models

The tools currently in use by local agencies vary in their complexity and approach to minimizing exposure to pathogens. Simulation of water quality conditions under various scenarios of untreated or partially treated sewage can be used. Comparison of the resulting water quality conditions with the established criteria can serve as the basis for a beach closure. A model was developed for the New York-New Jersey harbor that can predict water quality conditions that result from the bypassing of sewage at preselected locations. Beaches surrounding the discharge location are closed whenever the predicted indicator concentrations exceed the water quality criteria.

Advisories and closures for beaches and shellfish-harvesting areas that are based on water quality modeling are also issued in the states of Virginia, Rhode Island, and Washington. Computer models that predict bacteria indicator concentration by simulating the dominant mixing and transport processes in the receiving water range from simple to very complex. The Virginia Department of Health uses a simple mixing and transport model to predict water quality conditions surrounding wastewater treatment plant outfalls. *Review of Potential Modeling Tools and Approaches to Support the Beach Program* (U.S. EPA 1999) provides a detailed description of these and other tools, and their attributes, limitations, data requirements, and availability. A summary of the capabilities and applicability of these models is included in Table 7-3.

Table 7-3. Evaluation of model capabilities and applicability

Model	Combined PS/NPS	Real time and decision–making	Spills	Application to beach or shellfish closure	Ease of use	Input data required	Calib.	Developing guidelines	Pollutant routing
Rainfall-based	High	High	N/A	High	High	Low	Medium	Medium	N/A
Bypass	Low (PS)	High	High	High	High	High	Low	Medium	High
SMTM	Low (PS)	Medium	Medium	Medium	Medium	Low	Low	N/A	Low
PLUMES	Low (PS)	Low	Medium	Medium	Medium	Low	Low	Low	Low
CORMIX	Low (PS)	Low	Low	Low	Medium	Low	Low	Low	Low
JPEFDC	Medium (NPS/PS)	Low	High	High	Low	High	Medium	Low	High

N/A = Not applicable.

7.4.2 Rainfall-Based Alert Curves

A rainfall-based alert curve is a statistical relationship between the amount of rainfall at representative rainfall gages in the watershed and the observed bacterial indicator concentration at a specific beach area. This relationship is based on simple regression methods and the frequency of exceedance of simultaneous and representative observations of bacterial indicator concentrations and rainfall events. Bacteria criteria supporting the development of rainfall-based alert curves are generated from the water column concentrations obtained from probabilistic or targeted monitoring programs. Although these models do not explicitly account for point and nonpoint sources or fate and transport processes, they rely on a direct statistical relationship and provide simple, easy-to-use tools with reasonable accuracy.

Rainfall-based alert curves based on regression analysis have been used for preemptive beach closures in Milwaukee, WI; Stamford, CT; Sussex County, DE; and the Boston area. The overall objective of beach closure predictive tools is to minimize the population's exposure to bacteria. The tools currently in use vary in their complexity and approach to minimizing exposure, but are generally simple and reliable. The approach taken by the cities of Milwaukee and Stamford and the Delaware Department of Natural Resources and Environmental Control (DNREC) was regression analysis to relate rainfall to bacteria indicator concentration. Models developed on the basis of this approach are site-specific because they are derived from locally observed water quality and rainfall data as well as beach location/configuration relative to bacteria sources. Rainfall-based preemptive shellfish harvesting closures have been used for a number of years in Massachusetts, Rhode Island, and other states.

Rainfall-based alert curve models establish a statistical relationship between rainfall events and bacterial indicator concentrations. This relationship can then serve as a predictive tool to determine the need for beach advisories or closings based on predicted bacteria indicator concentrations. Several agencies have developed beach operating rules based on analysis of site-specific relationships between rainfall and water quality monitoring data. Delaware (DNREC 1997), Wisconsin (Pape 1998), and Connecticut (Kuntz 1998) have successfully used this approach (U.S. EPA 1999).

Rainfall-based alert curves are developed in three phases: collecting data, analysis of data (linking the rainfall events to bacterial indicators), and developing operating rules for advisories or closings of recreational waters. Although EPA is currently supporting continued efforts in research and development of these techniques, the Agency recommends that state and local beach managers consider developing scientifically based and easy-to-use site-specific decision rules based on the technical approach summarized below.

- Rainfall-based models are site-specific, and their development requires relatively large monitoring data sets of both rainfall and water quality. The overall relationship can be described by a statistical regression/estimation model. Depending on the number of rainfall stations considered and the number of rainfall characteristics (e.g., amount, intensity, duration, lag time), the relationship might require a more complex multiple-regression model. Because of the statistical nature of these models, they cannot distinguish between point sources and nonpoint sources of bacteria indicators and do not explicitly incorporate advection, transport, or decay processes. Because their use is limited to assisting in the development of decision rules for advisories and closings of recreational waters, these models do not attempt to provide the spatial and vertical distribution of bacteria indicators.

- Frequency of exceedance analysis is another rainfall-based method that can be used to develop rainfall-based alert curves. An exceedance is defined as any time the observed bacteria indicator concentration exceeds the action level, such as the state water quality standard, specified by a responsible agency. The objective of this method is to determine the minimum amount of rainfall that causes the bacteria indicator concentration to exceed the action level. This amount can be determined by dividing cumulative rainfall amounts over a period of 24 hours or more into segments that range from no rainfall to an upper limit that is representative of the rainfall record, types of storms, and season. For each rainfall amount category, the observed bacteria indicator concentration or the geometric mean of multiple samples is compared with the action level.

- After a relationship is established between rainfall amounts and bacteria indicator concentrations, developing decision rules for advisories and closings is the next step. An advisory or closing threshold is determined on the basis of the least amount of rainfall that would result in a violation of the action level. This method applies where historical rainfall data and water quality records exist. Decision rules should also be developed to include seasonal variation in rainfall. EPA is currently developing guidance on a number of linear regression techniques that can be used by beach managers to evaluate the need for preemptive advisories or closures.

7.4.3 How Does the State Make Attainment Decisions Using Predictive Models?

EPA recommends using predictive models for making WQS attainment decisions only when the state has collected rainfall data over time and has calibrated and verified the rainfall model. If the model then accurately demonstrates non-attainment under certain conditions and rainfall events, it can be used accurately for making attainment decisions. If the state only uses the model for precautionary closures, the data and model may not be appropriate for making attainment decisions.

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